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A Comparative study of different techniques in image Inpainting

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ABSTRACT

Digital image inpainting is a technique that restores an image by smoothly filling a hole in a purely automatic fashion. i. e. image inpainting fills the missing or damaged region in an image utilizing spatial information of its neighbouring region. The main goal of the Inpainting algorithm is to modify the damaged region in an image in such a way that the inpainted region is undetectable to the ordinary observers who are not familiar with the original image. Inpainting algorithm have numerous applications. It is helpfully used for restoration of old films and object removal in digital photographs. It is also applied to red-eye correction, super resolution, compression etc. This proposed work presents a brief comparative study of different image inpainting techniques like PDE based image inpainting, Exemplar based image inpainting, hybrid inpainting, and texture synthesis based image inpainting.

Key-words: Inpainting, Object Removal, Exemplar, PDE based inpainting, Texture Synthesis

1. INTRODUCTION

Recently, the Image Inpainting technology is a hotspot in graphics and that's based on Applied Mathematics. Image inpainting is an iterative method for repairing damaged pictures or removing unnecessary elements from pictures. This activity consists of filling in the missing areas or modifying the damaged images in such a way that the inpainted region cannot be detected by a casual observer. It has important value in a heritage preservation, film and television special effects production, removing redundant objects etc. In the fine art museums, Inpainting is carried out by professional artist as shown in Figure 1, and usually its very time consuming process because it was the manual process. Inpainting technique has found widespread use in many applications such as restoration of old films and paintings, object removal in digital photos, compression, image coding, transmission, removal of occlusions, such as large unwanted regions, red eye correction, super resolution etc. Image inpainting reconstruct the damaged region or missing parts in an image utilizing spatial information of neighbouring region. In digital images, we only have the image we are working on available to us and thus we are filling in a hole that encompasses an entire object. It is impossible to replace that entire object based on the present's information. So the aim of the inpainting algorithm is not only reconstruct what used to be in that hole, But instead to create a visually pleasing continuation of the data around the hole in such a way that it is not detectable by ordinary observer.

Image Inpainting:
Image inpainting refers to the process of filling in missing data in a designated region of the visual input, i.e. object of the process is to reconstruct missing parts or damaged image in such a way that the inpainted region cannot be detected by a casual observer.

1.1. Inpainting Problem

Inpainting problem is defined in terms of Mathematical point of view, In a sequence say S, given only a subsequence of it, X estimate the whole S as S' such that $I(S') = I(X)$, where I denotes the information. Here is a simple example to explain it more clearly. Suppose there is a sequence $\{1,2,3,4,X,6\}$ where X is the unknown element. If X is derived as 5, the whole sequence looks very "natural", for $I(X=5 \mid \{1,2,3,4,X,6\}) = 0$, i.e., it takes the exact value as we expected. However, if X is derived as 10, then the whole sequence does tell us something unexpected, and $I(X=10 \mid \{1,2,3,4,X,6\}) > 0$. In case of inpainting, the generated plausible regions are commonly looks natural which indicates that no additional information can be reproduced out of nothing related.

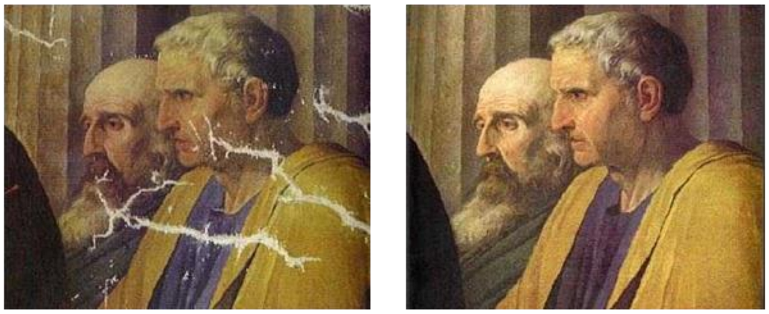

Figure 1
Example of manual inpainting performed by a professional artist professional artist

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So we define general principle of Image inpainting. Principle of Inpainting: Let $\Omega \subset D$ stands for the region to be inpainted as shown in Figure 2, and $\partial\Omega$ for its boundary. The objective is to fill the hole Ω with appropriate gray values by interpolating the data located at the neighbourhood in the surrounding region $\partial\Omega$ (e.g. boundaries of Ω).

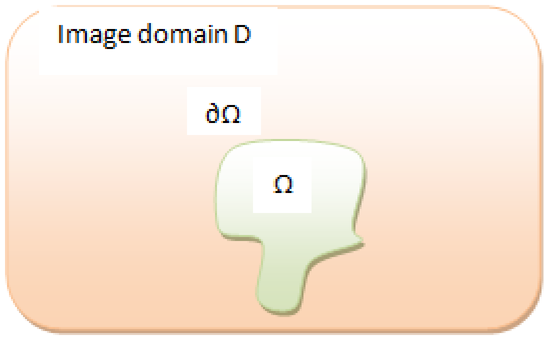

Figure 2
Principle of Inpainting

Most inpainting methods work as follows. As a first step the user manually selects the portions of the image that will be restored. Then image restoration is done automatically, by filling these regions in with new information coming from the surrounding area. In order to produce a perceptually plausible reconstruction, an inpainting technique must attempt to continue the isophote (line of equal gray value) as smoothly as possible inside the reconstruction region. In other words the missing region should be inpainted so that inpainted gray value and gradient extrapolate the gray value and gradient outside the region. Several inpainting methods are based on the above ideas. The first category of inpainting is Diffusion Inpainting. In this approach missing region is filled by diffusing the image information from the known region into the missing region at the pixel level. Basically these algorithms are based on theory of variational method and Partial Differential equation (PDE). The diffusion-based Inpainting algorithm produces superb results or filling the non-textured or relatively smaller missing region. The drawback of the diffusion process is it introduces some blur, which becomes noticeable when filling larger regions. All the PDE based inpainting models are more suitable for completing small, non-textured target region. The second category of Inpainting is exemplar-based Inpainting algorithm. This method of image Inpainting is an efficient approach to reconstructing large target regions. Exemplar-based Inpainting approach iteratively synthesizes the target region by most similar patch in the source region. These algorithms also overcome the drawbacks of PDE based inpainting. Also it removes smooth effect of the diffusion based Inpainting algorithm. This paper is organized as follows. Section-1 shows the Introduction of Image Inpainting problem. Section-2 describes the comparative study of different techniques for the image Inpainting which including exemplar based Inpainting, PDE based Inpainting, and Texture Synthesis based Inpainting, Hybrid Inpainting. Finally concluding remarks are given in Section-3.

Texture Synthesis:
Texture synthesis based algorithms are used to complete the missing regions using similar neighbourhoods of the damaged pixels. The texture synthesis algorithms synthesize the new image pixels from an initial seed. And then strives to preserve the local structure of the image.

2. DIFFERENT TECHNIQUES OF IMAGE INPAINTING

Nowadays, there are different techniques or approaches of image inpainting are available. So we can easily understand the methods and classify them into several categories as follows. I. Texture Synthesis based Inpainting. II. PDE based Inpainting. III. Exemplar based Inpainting. IV. Hybrid Inpainting. In this section we can briefly explain the concepts, usefulness, advantages, disadvantages, drawbacks, limitations of the Image Inpainting techniques.

2.1. Texture Synthesis based Inpainting

One of the earliest methods of image inpainting was to use general texture synthesis algorithms to complete the missing regions. The texture synthesis algorithms synthesize new image pixels from an initial seed and strive to preserve the local structures of the image. All the earlier Inpainting techniques utilized these methods to fill the missing region by sampling and copying pixels from the neighbouring area. Markov Random Field (MRF) is used to model the local distribution of a pixel and new texture is synthesized by querying existing texture and finding all similar neighbourhoods. Their differences lay mainly in how continuity is maintained between the inpainted hole and the existing pixels. These synthesis based techniques perform well only for a select set of images where completing the hole region with homogenous texture information would result in a natural completion. Then later, this technique was extended to fast synthesizing algorithm. This technique works by stitching together small patches of existing images referred to as image quilting. Bergen and Heeger, (1995) developed a parametric texture synthesis algorithm which can synthesize a matching texture, given a target texture. This was done by matching first order statistics of a linear filter bank which roughly match to the texture discrimination capabilities of Human Visual System [HVS]. Recently, a fast multi-resolution based image completion based and on texture analysis and synthesis was introduced fang et al., in 2000. In their method, the input image was analysed by a patch based method using principal component analysis (PCA) and a Vector Quantization (VQ) based techniques was used to speed up the matching process of the texture inside the hole region.

Hybrid:
Hybrid inpainting technique is also called as Image Completion. It is used for filling large target (missing) regions. And also preserves both structure and texture in a visually plausible manner. The hybrid approaches combine both texture synthesis and PDE based Inpainting for completing the holes.

Texture synthesis approaches (Efors et al.1999) can be categorized into three categories: Statistical (parametric), pixel-based and patch-based (non-parametric). Statistical methods are more likely to succeed in reproducing stochastic/irregular textures, but usually fail to reproduce structured/regular textures. On the other hand, pixel-based methods “build” on the sample texture pixel-by-pixel instead of applying filters on it, and their final outputs are of better quality than those of statistical methods, but they usually fail to grow large structured textures. Finally, patch-based methods “build” on a sample texture patch-by-patch as opposed to pixel-by-pixel, thus they yield faster and more plausible regular textures. A comparative study for patch-based texture synthesis algorithms has shown that “for handling special types of texture we have to develop the special purpose algorithms”. Taking this aim and the variety of algorithms for texture synthesis into consideration, we can conclude that there is no universal texture synthesizer is present. Still it remains a goal to be desire. The texture synthesis (Rane et al. 2002) based Inpainting perform well in approximating textures. These algorithms have difficulty in handling natural images as they are composed of structures in form of edges. Also they have complex interaction between structure and texture boundaries. In some cases, they also require the user to specify what texture to replace and the place to be replaced. Hence while appreciating the use of texture synthesis techniques in Inpainting, it is important to understand that these methods address only a small subset of Inpainting issues and these methods are not suitable for a wide variety of applications.

Application of Image Inpainting:
Applications range from the reconstruction of missing blocks introduced by packet loss during wireless transmission, reversing of impairments, such as cracks, scratches, and dirt, in scanned photographs and digitized artwork images, to removal/introduction of image objects such as logos, stamped dates, text, persons, and special effects on the scene.

2.2. PDE based Image Inpainting

Partial Differential Equation (PDE) based algorithm for Image Inpainting is proposed by Bertalmio et al, (2000). This algorithm is the iterative algorithm. Their model is based on nonlinear partial differential equations, and is designed to imitate the techniques of museum artists who specialize in restoration. In particular, Bertalmio elucidated the principle that good inpainting algorithms should propagate sharp edges in surrounding areas into the damaged parts that need to be filled in. The main idea behind this algorithm is to continue geometric and photometric information that arrives at the border of the occluded area into area itself. This is done by propagating the information in the direction of minimal change using isophote lines. This algorithm will produce good results if missed regions are small one. But when the missed regions are large this algorithm will take so long time and it will not produce good results. Then inspired by this work, Chan and Shen, (2001) proposed the Total

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Variational (TV) Inpainting model. This model uses Euler-Lagrange equation and anisotropic diffusion based on the strength of the isophotes. This model performs reasonably well for small regions and noise removal applications. But the drawback of this method is that this method neither connects broken edges nor greats texture patterns. The TV model then extended to CDD (Curvature Driven Diffusion- Chan and Shen, (2001)) model. In which it included the curvature information of the isophotes to handle the curved structures in a better manner. All of the above mentioned algorithms are very time consuming and have some problems with the damaged regions with a large size. PDE based technique has been widely used in number of applications such as image segmentation, restoration etc. These algorithms were focused on maintaining the structure of the Inpainting area. And hence these algorithms produce blurred resulting image. Another drawback of these algorithms is that the large textured regions are not well reproduced.

2.3. Exemplar Based Image Inpainting

As it was shown in above explanation, PDE based inpainting algorithms are not sufficient for faithfully reconstructing textured images, nor images with large missing areas. Thus, when inpainting is done with an image restoration purpose in mind, more complex techniques are required, as paintings are composed of both structures (i.e. primal sketches) and textures (i.e. regions with homogeneous patterns). Exemplar-based inpainting methods can overcome this drawback, being able to provide reasonably good quality results, even for large gaps, by combining the isophote driven inpainting with texture synthesis. The reconstructed visual quality and the reasonability of the filled image are mainly influenced by the filling order. Therefore, it's our belief that better performance is reachable via developing a robust priority function.

Exemplar based Inpainting iteratively synthesizes the unknown region i. e. target region, by the most similar patch in the source region. According to the filling order, the method fills structures in the missing regions using spatial information of neighbouring regions. This method is an efficient approach for reconstructing large target regions. Generally, an exemplar-based Inpainting algorithm includes the following four main steps: a) *Initializing the Target Region*: in which the initial missing areas are extracted and represented with appropriate data structures. b) *Computing Filling Priorities*: in this a predefined priority function is used to compute the filling order for all unfilled pixels say $p \in \partial\Omega$ in the beginning of filling iteration. c) *Searching Example and Compositing*: in which the most similar example is searched from the source region D to compose the given patch, say Ψ (of size $N \times N$ pixels) that centered on the given pixel p . d) *Updating Image Information,* in which the boundary $\partial\Omega$ of the target region Ω and the required information for computing filling priorities are updated. Numbers of algorithms are developed for the exemplar based image Inpainting. Such as, Bertalmio, (2003) developed a hybrid algorithm to combine the diffusion-based scheme and texture synthesis. This algorithm works well in recovering not only the geometrical structures but also the small texture regions. Then Drori, (2003) proposed a fragment-based image Inpainting algorithm that iteratively approximated, searched, and added detail by compositing adaptive fragments. The computation time of this algorithm is intolerable. Most of the new exemplar-based algorithms adopt the greedy strategy, so these algorithms suffer from the common problems of the greedy algorithm, being the filling order (namely priority) is very critical. Exemplar based Inpainting (Wong et al. 2008) will produce good results only if the missing region consists of simple structure and texture. And if there are not enough samples in image then it is impossible to synthesize the desired image.

Diffusion:
Diffusion is based on Heat equation (PDE), which propagates your pixels from cracks borders, like something hot (the image) moves into a cold area (the crack area).

2.4. Hybrid based Image Inpainting

The hybrid approaches combine both texture synthesis and PDE based Inpainting for completing the holes. The main idea behind these approaches is that it decomposed the image into two separate parts, Structure region and texture regions. The corresponding decomposed regions are filled by edge propagating algorithms and texture synthesis techniques. Hybrid inpainting technique is also called as Image Completion. It is used for filling large target (missing) regions. And also preserves both structure and texture in a visually plausible manner. One important direction we believe is more natural to the inpainting process is by structure completion through segmentation. This technique uses a two-step approach: the first stage is structure completion followed by texture synthesis (Rane et al. 2002). In the structure completion stage, segmentation, using the algorithm of, is performed based on the insouciant geometry, color and texture information on the input and then the partitioning boundaries are extrapolated to generate a complete segmentation for the input using tensor voting. The second step consists of synthesizing texture and color information in each segment, again using tensor voting.

3. CONCLUSION

In this comparative study, we review the existing techniques of image Inpainting. We discussed in this paper, a variety of different techniques of image Inpainting such as Texture synthesis based image Inpainting, PDE based image Inpainting, Exemplar based image Inpainting and Hybrid image Inpainting. Also we have provided a detailed explanation and description of the different techniques for image Inpainting which are used for filling the missing region making use of image. From this analysis, we also highlighted a number of shortcomings and limitations of these different techniques.

SUMMARY OF RESEARCH

It is observed that the PDE based image Inpainting algorithms cannot fill the large missing region and it cannot restore the texture pattern. The theoretical analysis proved that exemplar based Inpainting will produce good results for Inpainting the large missing region also these algorithms can inpaint both structure and textured image as well. But they work well only if missing region consists of simple structure and texture.

FUTURE ISSUES

Future study also focused on to develop such efficient algorithm that reduces computational cost and time required for Inpainting.

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